§31. Theory of Anomalous Transport in the Reverse Field Pinch

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Recently, efforts have been made to understand the anomalous transport coefficient in toroidal plasmas. A new method of plasma turbulence and anomalous transport, i.e., the self-sustained turbulence, seems to provide agreement with observations of various features [1]. It is also meaningful to examine the applicability of the transport theory to the reverse field pinch.

We employ the model of the high aspect ratio RFP. The toroidicity is neglected and the magnetic field is given by the Bessel function modelas

$$B_t = B_0 J_0(\zeta r), \; B_p = B_0 J_1(\zeta r) \; .$$

The magnetic field is characterized by parameters B_0 and ζ. The parameter ζ is in the range of $\zeta a \approx 3$. (a being the minor radius.) This configuration has the magnetic hill. The magnetic curvature κ and shear s are calculated as

$$\kappa = \frac{a}{B}\frac{dB}{dr} \simeq -\frac{\zeta^2 a\, r}{4}$$

$$s \simeq \frac{Rr}{B_t}\frac{d}{dr}\left(\frac{B_p}{r}\right) \simeq -\frac{1}{8}\zeta^3 R r^2$$

near the origin (R being the major radius.). Near the field reversal surface, we have $s \simeq -\zeta R$., and s remains of the order of R/a.

In the presence of magnetic braiding, the thermal transport coefficient of electrons was obtained as

$$\chi = \frac{1}{s^2}\left| R\beta' \kappa R/a \right|^{3/2} \left(\frac{c}{\omega_p}\right)^2 \frac{v_A}{R} M$$

where β is the ratio of the plasma pressure to the total magnetic pressure, v_A is the Alfven velocity and ω_p is the electron plasma frequency. The coefficient M denotes the enhancement factor of the magnetic braiding in evaluating χ_e. In the electrostatic limit, we have $M = 1$, and $M \approx m_i/3m_e$ for the case of magnetic stochasticity [2]. The condition for magnetic braiding has been obtained as $\beta \geq \beta_c$ with the critical pressure gradient $\beta_c \simeq 4 / \zeta^2 aR$. The condition for magnetic braiding is satisfied in the range of interest, $\beta_p \approx 0.2$, found in experimental observations.

The energy balance equation for the Ohmic heating plasma is given as

$$\langle\chi\rangle a^{-2} \langle n\rangle\langle T\rangle \simeq \langle\eta\rangle\langle J\rangle^2$$

where η is the resistivity and J is the current density. We write the resistivity as $\eta = \eta_0 Z_{eff} T^{-3/2}$ where η_0 is a universal constant and Z_{eff} includes both the effects of impurity collisions and a possible anomalous resistivity due to plasma turbulence.

From the energy balance equation , we have

$$T \propto Z_{eff}^{1/4} a^{-3/4} I_p n^{-1/4}$$

$$\beta_p \propto M^{-1/4} Z_{eff}^{1/4} a^{-1/4} N^{3/4} I_p^{-1}$$

where N is the number per unit length, $N = na^2$ and I_p is the plasma current.

These results are compared with experimental observations[3]

$$\beta_p \propto N / I_p$$

$$T \propto I_p^{0.8} n^{-0.2}$$

which agree well with the theoretical prediction.

References

1) Fukuyama A, Itoh K, Itoh S-I, Yagi M, Azumi M 1994 *Plasma Phys. Contr. Fusion* **36** 1385.
2) Itoh K, Fukuyama A, Itoh S-I, Yagi M, Azumi M 1994 "*Self-sustained magnetic braiding in toroidal plasmas*" Research Report NIFS-288.
3) Fujiwara M 1994 in *Plasma Physics and Controlled Nuclear Fusion Research 1992* Vol.4 p.23.